Coupled Ocean-Atmosphere Modeling of the Coastal Zone

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LONG-TERM GOAL

The long-range goal of this project is to improve our ability to understand and predict environmental conditions in the coastal zone.

OBJECTIVES

The primary scientific objectives of the proposed research are to use a coupled atmosphere--ocean model to investigate and quantify the interaction between the oceanic and atmospheric boundary layers and its effect on environmental conditions in the coastal zone. The main focus will be on boundary layer interactions under coastal upwelling conditions, in which cold, upwelled ocean surface water induces the development of stable internal boundary layers in the atmosphere and thereby reduces low-level winds and surface stress.

APPROACH

The approach used in this project is to combine numerical model results with in-situ and remote-sensing observations to understand and quantify physical processes in the coastal, coupled atmosphere-ocean and test their representation in mesoscale atmospheric models.

WORK COMPLETED

Work has continued on testing a coupled version of the COAMPS and ROMS models. Results from an idealized coastal upwelling scenario have been reported in a paper published in the Journal of Physical Oceanography (Perlin et al., 2007). Further model development has continued on generalizing the coupled model for domains with differing grid sizes. Extension of the model to more realistic coastal domains has begun with an initial case representing a coastal point or cape feature.

RESULTS

Work performed under this research grant has shown that the effect of SST gradient is significant for near-shore wind forcing. Perlin et al. (2007) performed idealized experiments using a coupled

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atmosphere/ocean model based on COAMPS and ROMS developed for the purpose of studying mesoscale air-sea interaction. Result from these experiments (Figure 1) suggest that air-sea interaction during coastal upwelling can reduce surface wind stress by as much as a factor of 2 over distances of about 20 km, as cold water outcrops near the coast and causes the development of an internal boundary layer in the atmosphere. The effects on surface stress are sufficiently strong that they can begin to affect the ocean upwelling circulation on relatively short timescales. Between 3 and 15 km from the coast, offshore Ekman transport in these simulations increased more rapidly with offshore distance, and vertical velocities at the base of the surface layer were stronger for the coupled case than for the uncoupled (ocean only) case. The coupled case also generated a thinner coastal surface layer with gradual seaward deepening. Overall, adjustment of surface Ekman divergence to the coastal boundary occurred over a slightly greater offshore distance in the coupled case than in the uncoupled case. Because of the wind reduction in the coupled case, vertical mixing in the upwelling zone was weaker, resulting in a shallower surface mixed layer. This delayed the merging of the surface and bottom boundary layers over the inner shelf and allowed further inshore propagation of the bottom upwelling front. Within 2 km off the coast, local cross-shore transport estimates were slightly greater and SST slightly cooler for the coupled case. Weaker near shore wind stresses in the coupled case also resulted in consistently smaller alongshore transport in the oceanic surface layer.

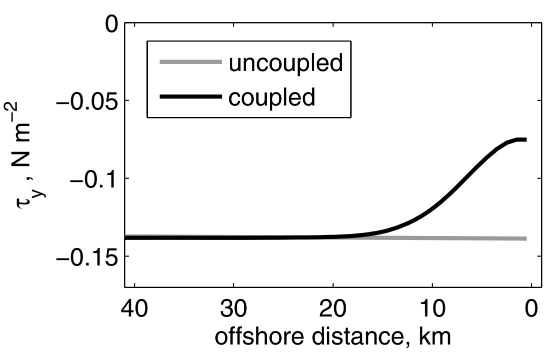

Figure 1. Surface meridional wind stress at the end of a 72-h run for two simulations. Note the factor of 2 reduction in wind stress at the model coastline. (from Perlin et al. 2007).

Results from the idealized channel flow simulations support the general hypothesis that SST variability can have significant control over the surface wind stress. However, observations (e.g., Perlin et al., 2004) show that variations in coastal topography can also cause large changes in the coastal wind forcing. Therefore, including coastal variations into the coupled simulation model was a principal goal in our most recent proposed effort.

As in the channel flow case, we first examined an idealized scenario for topographic variability for two coastal bends as shown in Figure 3a. Periodic boundaries were again used in the north-south direction with open boundaries along the east and west. The advantage in this approach over a full, realistic simulation of the coast line is the ability to distinguish the role of the terrain and SST variations from other potential influences, such as land surface variability, diurnal heating, and unresolved topographic features.

Preliminary coupled simulations using this domain, in which the ocean model is first forced with fixed winds for several days and then coupled to the atmospheric model, show a number of features connected with the coastline variations and the decoupled boundary layer over the upwelled water

(Figure 2). The most immediate impact of the coastline variations is on the width of the upwelling region. South of the first bend, cooling extends more than 60 km offshore, whereas south of the second bend, the upwelling region is less than 40 km wide. Small-scale variations in the SST pattern are also evident as demonstrated by the cross section of SST at line B.

Downstream of the first bend, there are large, orographically forced variations in wind stress that are independent of SST, with superimposed variations arising from the SST gradients and air-sea interaction processes (Figure 3). Wind stress in the lee of the first bend is greater than 0.2 N m^{-2}, whereas the combination of orographic and air-sea coupling effects leads to a wind stress less than 0.05 N m^{-2} just downstream from the second bend.

Our results from these idealized simulations suggest that coupling in actual coastal scenarios is a complicated process involving both coastal configurations and internal marine boundary layer dynamics. Future work will extend these results by including analysis of new cases, moving toward a comprehensive understanding of the coastal boundary layer including diurnal variations and clouds.

(a) (b)

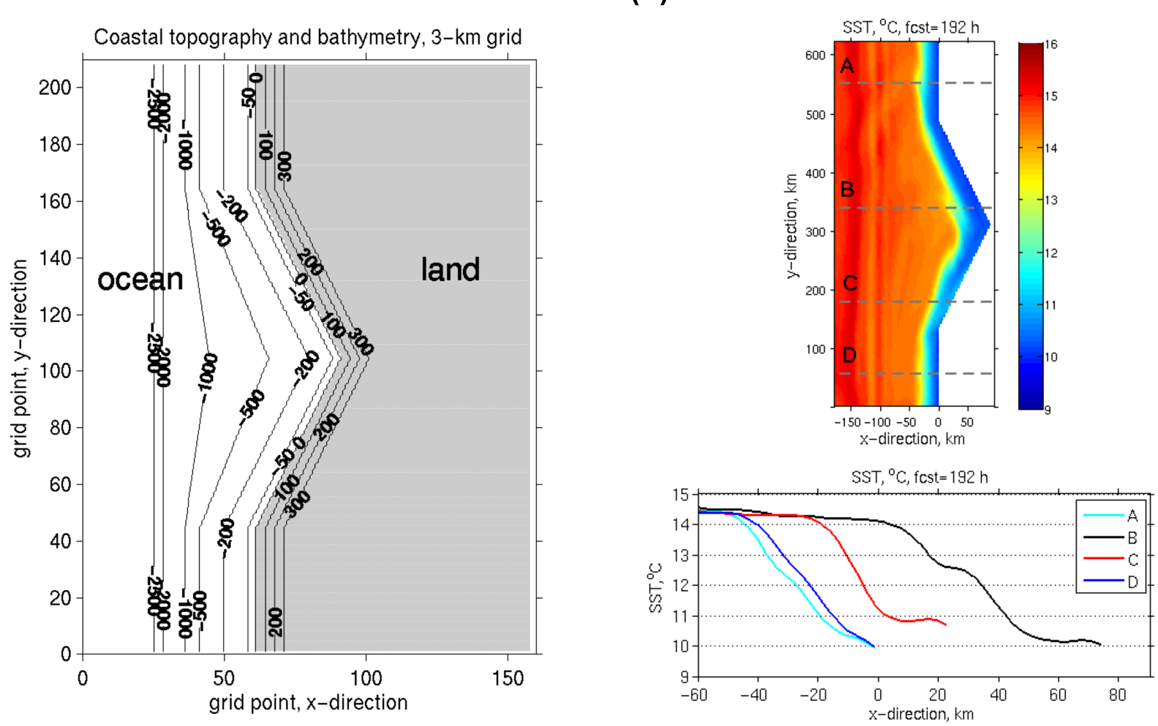

Figure 2. (a) Idealized coastline and bathymetry with a bend, and (b) SST (^{o}C) after 192 hours of simulated time.

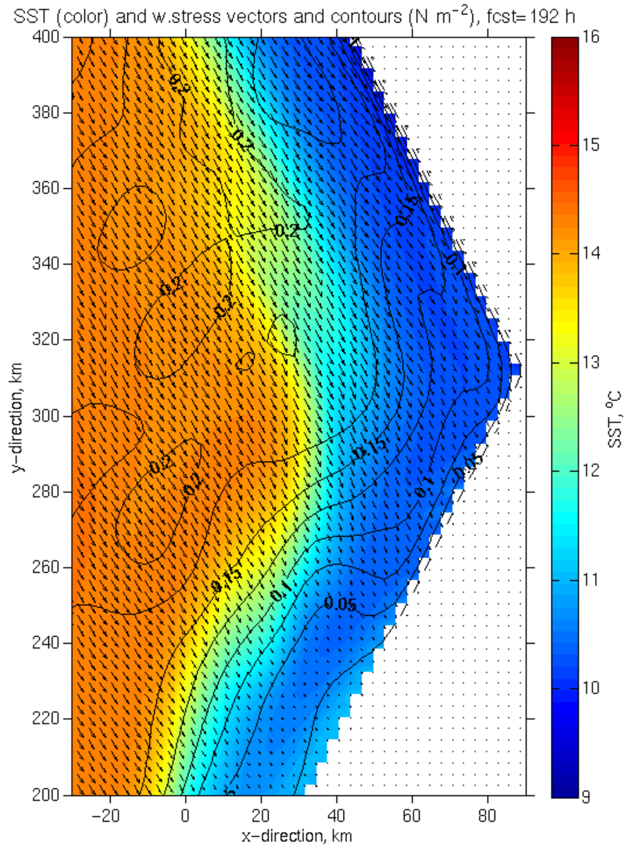

Figure 3. Sea-surface tempearture (^{o}C shaded) and wind stress (N m^{-2}, vectors and contours) after 192 hours of simulated time. Note the sharp decrease in wind stress from north to south along the coast.

Development and documentation of the coupled model will continue with adaptation of the Earth System Modeling Framework (www.esmf.ucar.edu). N. Perlin is currently involved with a NOPP project to couple a sediment transport model with ROMS using ESMF as the overall model framework. This work complements our coupled modeling efforts and will leverage further development of the model interface.

TRANSITIONS

The coupled model code has been made available to the general community. For example M. Spall (WHOI, personal communication) is using the model to study open-ocean air-sea coupling in the North Atlantic.

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